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Abstract

HEAVY-WATER POWER REACTORS AND ORGANIC-COOLED POWER REACTORS

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Nuclear power plants employing reactors moderated with heavy water and using a number of different coolants have been investigated extensively in the United States in the past five years. The power plants studied are of progressively larger outputs, the majority being of 500 MW(e) size. The reactors use pressure tubes and employ graded irradiation of the fuel in order to limit excess reactivity. On-power fueling also is a feature of many of the designs. The coolants are liquid D_2O, boiling D_2O, fog H_2O, pressurized CO_2, and organic fluid. In the present paper, estimated capital, operating, and fuel-cycle costs are given for each type of coolant and for several financing schemes. Fuel-cycle costs in the range of 1 mill per kilowatt hour or lower are obtained for most coolants with total power costs in the range of 5 to 6 mills/kwh using utility-company financing. Lowest costs are obtained when the fuel is slightly enriched uranium at U. S. prices. Energy costs for natural-uranium fuel also are shown. The effect of chemical processing charges and Pu credit on the power cost is reviewed, and the cost advantage or penalty for a throw-away fuel cycle is shown.

Fuel-element designs include cylindrical UO_2 pellets clad in metallic jackets, massive annular cylinders fabricated by vibratory compaction of UO_2, and metallic uranium clad with bonded jackets. Results of studies are given that explore the potential of reactors fueled with thorium and U-233 and moderated with D_2O for operation as breeders.

Organic cooling has received special attention since the studies show that heavy-water moderation with organic cooling will yield both low capital and fuel-cycle costs. Experiments have shown that the formation of deposits (fouling) on fuel-element surfaces has been controlled by maintaing coolant purity below 5 parts/million ash by means of distillation, filtration, and

adsorption. The feasibility of fabricating fuel elements clad with sintered aluminum power (SAP or APM) has been demonstrated. Operation of the Organic Moderated Reactor Experiment, in which 98 SAP-clad UO_2 prototype fuel rods were irradiated to 11 000 MWd/tonne at cladding surface temperature up to 850F (450C) without any fuel failures or deposition of fouling films gives concrete evidence of the effectiveness of coolant purity control and the integrity of the SAP-clad fuel. Operation of the Piqua, Ohio Nuclear Power Plant since November 1963 has confirmed the feasibility of reactor cooling by organic fluid in systems using carbon steel as a material of construction. Studies of the D_2O-moderated organic-cooled system have indicated advantages for the uranium carbide fuel. Out-of-pile tests have shown the compatibility of properly-treated SAP with uranium carbide fuel. The feasibility of zirconium alloys for organic service still requires definite confirmation. Alloys and protective surface layers are promising.

The role of the heavy water reactor in conserving fissile material resources is reviewed, including its potential for Pu recycle. Also, the effect of the low inventory of fissile material of the heavy-water reactors on uranium utilization is illustrated, in particular where the heavy-water reactor is combined with breeder systems.

Since there appears to be no size limitations to heavy-water-moderated reactors, estimates of energy costs for power plants of 1 000 MW(e) and larger have been made and show a continuing trend to lower capital and fuel costs.